Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

# AVIATION INVESTIGATION REPORT
# A14W0177

## RIGHT MAIN LANDING GEAR COLLAPSE

## JAZZ AVIATION LP (DBA AIR CANADA EXPRESS)
## DHC-8-402, C-GGBF
## EDMONTON INTERNATIONAL AIRPORT, ALBERTA
## 06 NOVEMBER 2014

Canada

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Edmonton International Airport
Edmonton, Alberta
06 November 2014

## *Summary*

The Jazz Aviation LP (doing business as Air Canada Express) Bombardier DHC-8-402, registration C-GGBF, serial number 4433, operating as flight JZA8481, departed from Calgary International Airport (CYYC) with an intended destination of Grande Prairie, Alberta. During the takeoff roll, the number 3 tire of the main landing gear failed. The flight was diverted to Edmonton International Airport (CYEG); aircraft rescue and firefighting equipment was standing by for the landing on Runway 02. On touchdown at 2030 Mountain Standard Time, the right main landing gear collapsed. Upon contact with the ground, all of the right-side propeller blades were sheared, and 1 blade penetrated the cabin wall. The aircraft came to a stop off the right (east) edge of the runway surface. Passengers and crew evacuated using all 4 exits. Three passengers sustained minor injuries. There was no post-accident fire. The accident occurred during the hours of darkness.

*Le présent rapport est également disponible en français.*

# Factual information

## History of the flight

Jazz Aviation LP (doing business as Air Canada Express) flight JZA8481 departed from Calgary International Airport (CYYC) at 1947[1] 06 November 2014 on a scheduled flight to Grande Prairie Airport (CYQU), Alberta.

During takeoff, as the Bombardier DHC-8-402 (registration C-GGBF, serial number 4433) aircraft approached rotation speed (Vr), there was a noticeable vibration that ended once the aircraft was airborne. Once the landing gear was retracted and the aircraft was established in the climb, the flight crew discussed the vibration. The cabin crew informed the pilots that a tire had blown.

Company maintenance and operations crews at its dispatch centre were contacted through the company's very high frequency channels. Because of strong crosswinds, returning to CYYC was not an option, and a decision was made to land at Edmonton International Airport (CYEG) and to switch aircraft owing to the ruptured tire. Maintenance personnel recommended that a hard landing be avoided.

Air traffic control arranged for the aircraft to level at 13 000 feet above sea level. The cabin crew confirmed that the number 3 tire had blown and revealed that something had struck the aft fuselage.

**Photo 1. The occurrence aircraft at the accident site**

Throughout the approach phase of the landing sequence, the landing gear control panel indicated that the landing gear was down and locked. The aircraft touched down very lightly on Runway 02 at CYEG. As the wheels spun up, a pronounced vibration shook the aircraft 2.4 seconds after initial touchdown; while the nose wheel of the aircraft was still airborne, the right main landing gear (MLG) collapsed. The right-side propeller blades struck the runway, and all were sheared on contact. One large section of a propeller blade penetrated the aircraft cabin next to passenger row 7. At the same time as the propeller contact, the nose landing gear came down hard and its tires ruptured. The aircraft slid slightly to the right and came to a stop off the right edge of the runway, approximately 3200 feet past the touchdown point (Photo 1).

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1 All times are Mountain Standard Time (Coordinated Universal Time minus 7 hours).

## *Digital flight data recorder*

Data from the aircraft's digital flight data recorder (DFDR) were analyzed at the TSB Laboratory. The focus of the analysis was on the takeoff roll, when the tire failed, and on the subsequent collapse of the right MLG on landing. The DFDR had recorded tri-axial accelerations, which provided information on the aircraft vibrations when the tire failed. The landing gear data consisted of a number of discrete signals that indicated the status of the uplocks and downlocks for the nose landing gear and MLGs, the landing gear handle position, and the weight-on-wheels (WOW) state.

The landing gear was selected down as the aircraft descended through approximately 7800 feet[2] above sea level before intercepting the instrument landing system for Runway 02. The aircraft was approximately 18 nautical miles from CYEG at this time. Both main and nose landing gears changed from "up and locked" to "down and locked," as they normally would. No master warning or master caution alerts were displayed during the approach, and there were no abnormal indications concerning the hydraulic system pressure or fluid quantity.

Information from the landing gear manufacturer (Goodrich Aerospace Canada Ltd.) indicates that the discrete output for MLG downlock activates when (1) either the primary or alternate system downlock sensor for each main gear measures "down and locked" and (2) at least 1 downlock sensor of each main gear is not faulted.[3] Subject to these conditions, if the MLG downlock releases on either gear, the discrete output deactivates (i.e., the MLG state becomes "not down and locked").

There was no indication of any abnormal condition other than the ruptured tire. As a consequence, the crew expected a normal landing and followed all the proper procedures for that expectation. No emergency was declared, nor was aircraft rescue and firefighting equipment requested. However, the equipment did roll out to meet the aircraft during the landing.

A momentary MLG WOW was recorded at 118 knots calibrated airspeed (KCAS). The power levers were retarded to flight idle at initial MLG WOW, with the recorded vertical load factor at approximately +1.05*g*.[4] Approximately 1.5 seconds later, full MLG WOW was recorded at 114 KCAS; the recorded vertical load factor was +1.07*g*. This is an indication of very light touchdown forces and a soft landing. At this point, the power levers were retarded below

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2 This altitude was based on the altimeter setting of 29.62 inches of mercury reported by air traffic control; at this point, the altitude above the runway was approximately 5400 feet.

3 Goodrich Aerospace Canada Ltd., Document DHC8PROX-ICD V (15 November 2012), p. 33.

4 *g* force is a measure of vertical acceleration due to gravity. An acceleration of 1*g* is 9.8 $m/s^2$.

flight idle, and the ground spoilers were extended. The propeller beta discrete signal subsequently recorded a change into "reverse."[5]

The aircraft rolled suddenly to the right 2.3 seconds after the second MLG WOW indication, which was consistent with the right MLG collapsing; the airspeed at that time was approximately 105 KCAS. During the gear collapse, the power levers were being retarded into reverse. The MLG WOW changed back to "air," and the MLG "down and locked" discrete signal, which is sampled every 4 seconds, was changing from "down and locked" to "not down and locked." An aural warning tone activated, as well as several discrete parameters on the DFDR, including the master warning, the master caution, and the "touched runway" discrete signals. A vertical acceleration peak of 2.68*g* was recorded as the aircraft rolled to the right and struck the ground. No previous warnings or cautions had been recorded on the DFDR nor had any abnormal indications been associated with the hydraulic system or the landing gear.

## *Weight and balance*

The investigation found that the aircraft was operating within all weight and balance limits. The crew calculated the landing weight as 61 800 pounds and flew with landing reference speeds for a maximum landing weight of 62 000 pounds.

## *Flight crew*

Records indicate that the flight crew was certified and qualified for the flight in accordance with existing regulations.

The captain had 59 hours on Q400 series Dash 8 aircraft and 11 998 hours on older versions of the Dash 8, for a total of 18 223 hours of experience. The captain had flown a total of 16.1 hours in the previous 7 days and had had a full day of rest before the flight on the evening of 06 November 2014.

The first officer had 1500 hours on Q400 series aircraft and a total of 2800 hours of experience. The first officer had flown a total of 16.6 hours in the last 7 days and had had a full day of rest before that evening's flight.

The crew was adequately rested, having had sufficient time off duty during the pairing.

The first officer was the pilot flying for the sector, and the captain was the pilot monitoring.

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5 The propeller beta discrete signal records "reverse" when the power levers are retarded approximately 2½° below flight idle. This output indicates that the propeller blade angles have decreased below flight idle settings, and the propeller ground range lights should turn on.

## *Operator information*

Jazz Aviation LP (doing business as Air Canada Express) operates under Subpart 705 of the *Canadian Aviation Regulations* (CARs). The company has been compliant with requirements for a safety management system under Part 1, Subpart 7 of the CARs since 2007. It operates a fleet of 125 aircraft, including the Bombardier Dash 8, Regional Jet, and Q400 NextGen series airplanes; the fleet includes 21 of the Q400 airplanes.

## *Weather*

At 2113, 17 minutes before the accident, a special aviation routine weather report (SPECI METAR) was issued, which stated that the wind was 290° true at 4 knots, with direction variable between 270° to 340° true. Visibility was 15 statute miles with few clouds at 1000 feet above ground level (agl), broken clouds at 5800 feet agl, and an overcast layer at 11 000 feet agl. Temperature was 5 °C, the dew point was 3 °C, and the altimeter setting was 29.61 inches of mercury.

At 2134, 4 minutes after the aircraft came to rest, another SPECI METAR was issued. It stated that the wind was 320° true at 7 knots, with visibility of 15 statute miles in light rain showers, few clouds at 100 and 3000 feet agl, broken clouds at 4800 feet agl, and an overcast layer at 7500 feet agl.

## *Maintenance*

A thorough check of the recent maintenance records and all actions relevant to the components in this occurrence was carried out. All of the systems and components directly involved were inspected and/or tested in detail. No anomalies were found. All records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

The occurrence aircraft was equipped with a tire manufactured by Dunlop Aircraft Tyres Ltd. that had been retreaded once. Immediately after the accident, management of Jazz Aviation decided to mitigate any possible future damage from MLG tires and no longer use retreaded tires on the MLG of its DHC-8-Q400 fleet, effective 10 November 2014.

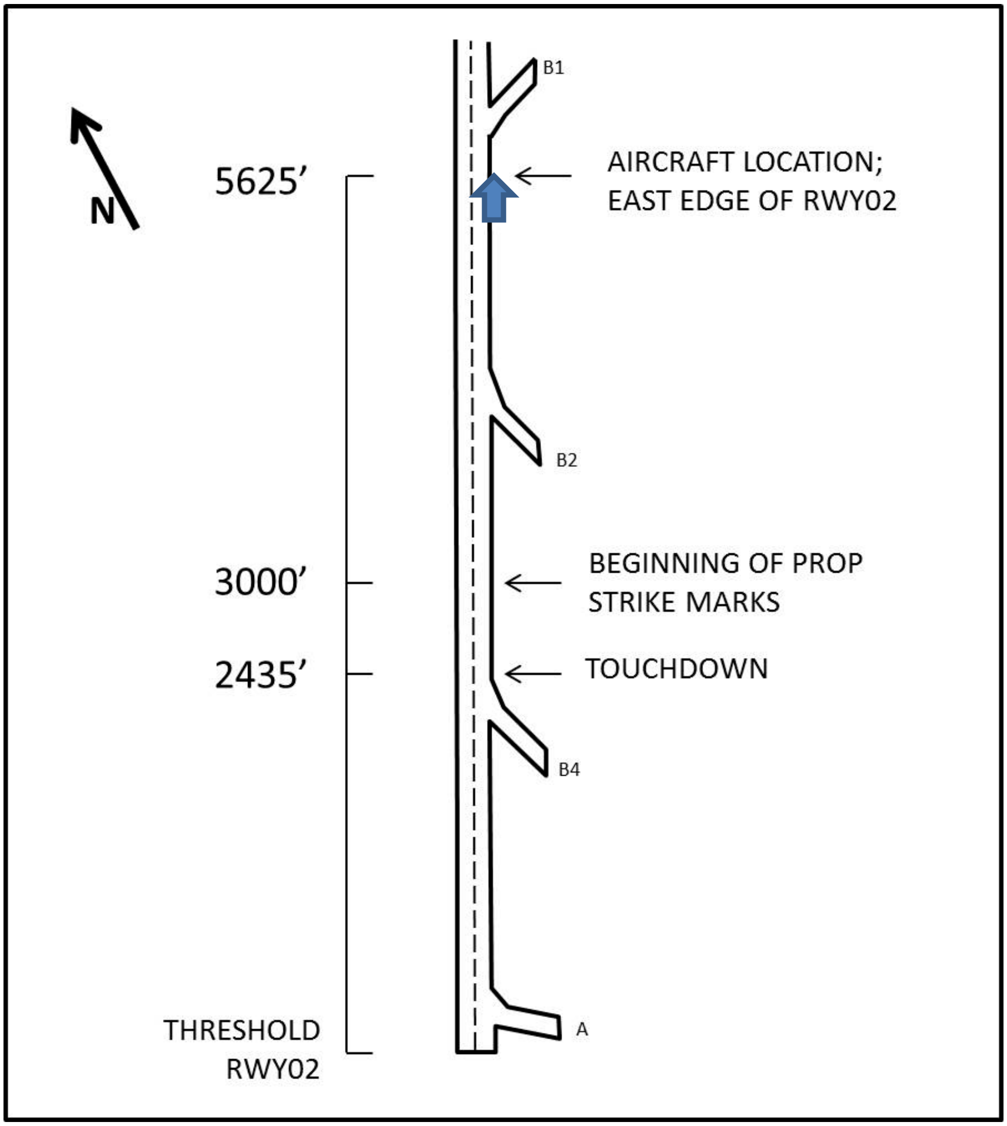
## *Accident site and wreckage trail*

The area of the propeller strike marks was about 40 feet long, with approximately 2 feet between marks (Figure 1). Based on the propeller speed of 1020 revolutions per minute (rpm), which had been briefed by the crew and recorded on the DFDR, these strike marks indicated an approximate ground speed of 120 knots. However, the DFDR recorded an airspeed of 105 KCAS at the time of the collapse, and the DFDR with WOW recorded an airspeed of 118 KCAS just before the collapse.

The nose wheel left marks on the runway indicating that it had come down hard at the same time as the propeller strikes began. The distance from the propeller strike marks to the nose gear contact point was the same as the distance on the aircraft from the propeller rotational plane to the nose gear location.

The aircraft landed slightly right of centre line on Runway 02 at 2435 feet from the threshold. Throughout the landing phase, the landing gear collapse, and the subsequent slide to a stop, the aircraft maintained runway heading. It came to rest 3190 feet after touchdown. The left side main wheels were still on the runway. The left side of the fuselage was on the right-hand edge of the runway asphalt, still parallel to the runway heading. The right wing was touching the ground. The nose landing gear had collapsed rearward during the slide and was approximately 5 feet from the right-hand edge of the asphalt.

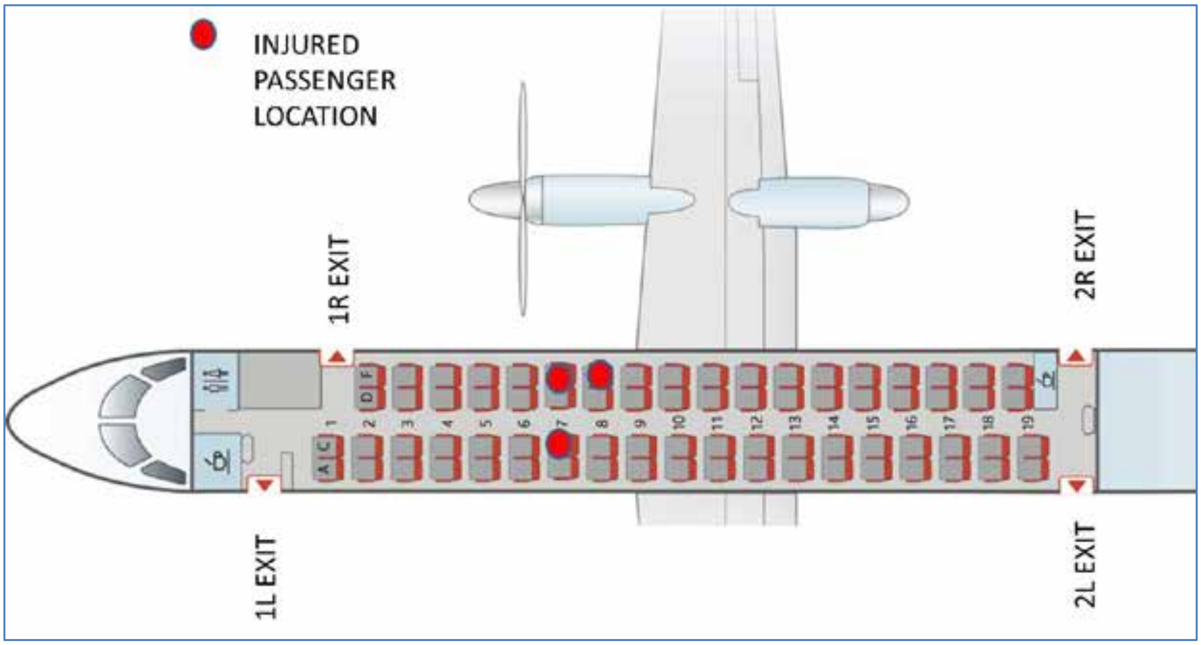
**Figure 1. Landing path of Jazz 8481 on Runway 02**




## *Injuries*

Passengers in seats 7F, 8F, and 7C were injured as a result of the partial propeller blade that punctured the fuselage (Figure 2); these injuries were consistent with plastic pieces in the cabin interior (side wall, window, etc.) blowing into the seating area. There were also blunt-force injuries, abrasions, and small puncture wounds. There were no injuries related to the evacuation.

**Figure 2. Jazz 8481 cabin layout showing location of injured passengers**




## *Evacuation*

The aircraft exits and emergency evacuation windows were certified in accordance with the CARs Part V — Airworthiness (525).[6] A smoky haze from an unknown source or sources filled the cabin during the evacuation but did not hamper visibility. Emergency lighting was on.

The first passenger who evacuated exited the aircraft through the 2L door 23 seconds after the aircraft came to a stop. Passengers evacuated through all 4 exits. The 1L (main-entry airstair door) was the last to be used, because of difficulties in opening the door. The door is counterweighted and, given that the aircraft had rolled to the right side, required the efforts of both flight crew to push it open. The 2R door also required extra work to open. The rear flight attendant had to exit by the 2L door and walk around the aircraft to ensure from the outside that the gust lock on the 2R door would lock, securing the door open, before passengers were permitted to use the 2R door to evacuate.

Sixteen seconds after the aircraft came to a stop, both flight attendants began to command passengers to evacuate the aircraft. All passengers were out of the aircraft in less than 1 minute.

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[6] *Canadian Aviation Regulations* (CARs) sections 525.803, 807, 809, 811, 812, 813, and 815.

Twenty-six seconds after the aircraft came to a stop, the captain made a command to evacuate out of the right side of the aircraft, but no passengers or flight attendants heard the command. TSB investigators tested the intercom, which was found to be functioning normally.

One passenger from mid-cabin attempted to take carry-on luggage when proceeding to the aft of the aircraft. Other passengers encouraged this individual to leave the luggage behind. This caused a slight delay in passengers heading to the aft exits.

Another passenger had difficulty removing the seat belt and was struggling to find the latch. An evacuating passenger saw the passenger struggling and opened the seat-belt latch for this individual.

Once outside, passengers gathered on both sides of the aircraft in groups.

## *Edmonton International Airport emergency response*

The *Emergency Procedures Manual*[7] for CYEG specifies measures to be taken for the evacuation of passengers from the scene of any accident or incident. The airport authority has a call-out system that directs all available 30-passenger parking-lot shuttle buses to assist immediately in an evacuation; all taxis present may be used as well. On the evening of the occurrence, 5 buses and 3 ambulances attended the aircraft, with 10 additional ambulances responding and standing by at a staging area. The buses were called out approximately 6 minutes after the last evacuees were out of the aircraft, and all were on scene and boarding passengers 13 minutes later. The buses began departing the scene approximately 31 minutes later.

## *Jazz Aviation* Q400 Quick Reference Handbook

The Jazz Aviation *Q400 Quick Reference Handbook* (QRH)[8] is designed to help trained pilots verify that the proper procedures have been carried out in normal, abnormal, and emergency situations. The information in the QRH is derived from the Bombardier aircraft flight manual (AFM) and aircraft operating manual, and from the *Transport Canada Aeronautical Information Manual*.[9]

The QRH makes no reference to any specific procedures in the event of a damaged tire.

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7 Edmonton International Airport, *Emergency Procedures Manual* (Fall 2014), pp. 14 and 37.

8 Jazz Aviation LP, *Q400 Quick Reference Handbook* (QRM) (revised 30 January 2014).

9 Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* (TC AIM) 2014-2 (effective 16 October 2014 to 02 April 2015).

## *Aircraft flight manual*

Although the AFM has a section on emergency landings, it does not address landing with a flat tire. The crew carried out a normal landing, based on the information in the QRH and AFM, and on information provided by the cabin crew and maintenance staff.

## *Company operations manual*

The company operations manual makes reference to 3 landing classifications: normal, abnormal, and emergency landings. During a normal landing, no emergency preparations are necessary, and the cabin is prepared for a routine landing. An abnormal landing requires a high alert level. The cabin crew remain ready for a possible emergency situation by listening to all public address announcements on the intercom system, following the captain's instructions, etc. An emergency landing involves a serious situation that requires the cabin crew to follow all emergency procedures under the captain's direction. Cabin crew prepare the passengers and cabin for the landing using the emergency landing procedures checklist.

On 17 June 2014, Bombardier issued Flight Operations Service Letter (FOSL) DH8-400-SL-32-013B,

> to remind Flight Crew of the appropriate procedures for operating the landing gear utilizing the normal or alternate extension systems. Responding to Operator's requests, this FOSL is intended to provide possible considerations for Flight Crew if confronted with an abnormal landing gear configuration, which cannot be rectified with the existing Aircraft Flight Manual (AFM) procedures ....[10]

The service letter contains actions for the crew's consideration in the event of an unsafe condition of the landing gear; these include moving passengers from seats in the plane of the propellers and reseating them elsewhere in the cabin. During the occurrence flight, there was a fully safe "gear down and locked" indication, so moving passengers was not warranted or required by the FOSL guidance material referred to by the flight crew before the landing.

## *Propellers*

At initial contact, the propellers shattered into small pieces near the tips; then, as they came closer to the ground, they sheared at the hub. This is an expected and normal mode of failure when composite blades contact hard objects. A reinforced area on the fuselage (called the

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[10] Bombardier Aerospace, DH8-400-SL-32-013B, Flight Operations Service Letter, Subject: Landing Gear, Model: Dash 8, Applicability: DHC8 Series Q400 (17 June 2014), Purpose, p. 1.

"ice shield") is designed to protect against ice shed from the propeller blades during icing conditions but is not designed to resist impact from objects such as debris from the propeller.

## Tire failure

The number 3 MLG tire, deflated but still mounted on the wheel, was submitted for examination to the TSB Laboratory. The fracture surfaces on both the casing and the tread fragments showed characteristics consistent with rapid tearing, except for a few locations where abrasion damage caused by contact with the runway was observed. No sign of cuts or punctures was found on the recovered fragments. The number 3 MLG tire failed due to an impact break, most likely caused by running over a hard object at high speed during takeoff.

The investigation determined that some airlines have found that the number 3 main tire fails more frequently than other tires on this Q400 aircraft type. Aircraft that have not had a passenger bridge sometimes make hard right turns under power while departing from the gate, and use the right-side brakes to assist in the manoeuvre. This hard braking and turning may cause an extreme shearing force on the tread area and on the sidewalls of the number 3 tire in particular, because it is the pivot point.

## Landing gear system description and operation

Illustrations of the MLG are provided in Appendix A.

The landing gear selector lever and the proximity sensor electronic unit (PSEU) control the operation of the landing gear. The number 2 hydraulic system supplies the power to the landing gear.

Hydraulic retraction or extension starts when the landing gear selector lever is moved to the desired position. The PSEU checks the status of the MLG and the MLG doors, and compares it with the command selected. The PSEU verifies the "down and locked" status of the gear through signals sent to it by 2 proximity sensors on each main gear, as well as an uplock sensor and a door sensor. When these sensors and targets are close together (read by the PSEU as "NEAR"[11]), this indicates that the gear is down and in a locked condition. When the gear is not locked down or is in transition, the proximity sensors are read by the PSEU as being in a "FAR"[12] condition. The PSEU also controls the hydraulic sequences to either fully extend or fully retract the landing gear. The status of the landing gear and the landing gear doors is shown in the cockpit by the indicator lights on the landing gear control panel. A "landing gear inoperative" (LDG GEAR INOP) caution light on the Caution and Warning panel indicates a fault in the landing gear retraction and extension system.

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11 Aircraft Maintenance Manual – System Description Section 32–61–01–001 Proximity Sensor Electronic Unit

12 Ibid.

- The landing gear starts to extend when the landing gear selector lever is unlocked and moved to the down (DN) position.
- The down solenoid of the selector valve receives electrical power.
- The selector valve supplies aircraft hydraulic system pressure and flow into the extend side of the landing gear hydraulic system.

*Main landing gear extension*

When the landing gear selector lever is moved to the down position, the 2 MLG solenoid sequence valves (SSVs) remain de-energized. At the start of the normal MLG extend sequence, these de-energized SSVs supply hydraulic pressure to the retract side of the MLG aft doors actuators, opening the MLG aft doors. When the MLG aft doors are approximately 93% open, the MLG aft doors linkage operates the mechanical sequence valve. The valve supplies hydraulic pressure to the uplock release actuators and to the down side of the MLG retraction actuators. The MLG then starts to travel to the down and locked position.

Three proximity sensors are used to monitor the MLG extension sequence. Each MLG has 2 down-and-locked sensors and 1 MLG aft-doors-closed sensor. When the PSEU receives input signals that the MLG is down and locked, the PSEU energizes the SSVs.

Pressure is then supplied to the MLG aft doors actuators to close the MLG aft doors. At approximately 7% reverse travel of the MLG doors, the mechanical sequence valves close. This action isolates the MLG retraction actuator from the rest of the hydraulic system. In-line restrictors keep the down side of MLG retraction actuators pressurized to 3000 pounds per square inch (psi) at the end of the extension sequence.

When the landing gear is down and locked, the SSVs and the down solenoid of the selector valve are kept in an energized condition. This condition maintains hydraulic pressure on the down side of the retraction actuators and the down side of the MLG unlock actuators, which helps keep the over-centre lock links in a position that locks the stabilizer brace.

*Landing gear control panel*

The landing gear is controlled and monitored from the landing gear control panel, located on the right side of the engine display on the forward instrument panel in the flight deck. The panel has a landing gear selector lever, a lock-release selector lever, landing gear and landing gear door advisory lights, and a landing gear warning horn/mute test switch. The landing gear is commanded to the up or down position with the landing gear selector lever. An amber light in the landing gear selector lever is illuminated when the landing gear position does not agree with the landing gear selector handle position or when any of the landing gear doors are not closed.

### *Landing gear selector valve*

The landing gear selector valve is a self-contained assembly with 2 solenoid valves. It controls hydraulic pressure to position a directional control valve that is spring-centred. The position of the valve controls the supply of hydraulic pressure to either the up or down hydraulic circuits of the landing gear system. The landing gear system can be configured for either normal retraction or extension.

### *Main landing gear unlock actuator*

The MLG unlock actuator has 2 ports, to which hydraulic lines are attached and sealed with O-rings. The MLG unlock actuator is attached to the MLG stabilizer brace assembly. The unlock actuator's primary function is to unlock the stabilizer brace. When the MLG is down and locked, this actuator also provides down-force, helping the lock links to stay in an over-centre position.

### *Stabilizer brace*

The stabilizer brace is a 2-piece folding structural component. The occurrence aircraft's assembly was part number 46400-29. There had been 2 previous versions of the brace, which had been modified as design issues were identified and rectified. The stabilizer brace keeps the yoke and the shock strut in position when the MLG is in the extended or retracted position. The forward section of the stabilizer brace is attached to the airframe structure in the forward section of the wheel well with 2 lubricated hinge points. The aft section of the stabilizer brace is attached to the yoke, also with 2 lubricated hinge points.

Attached between the 2 sections of the stabilizer brace is an over-centre link sub-assembly that supplies a mechanical lock for the MLG in the down position. The mechanical lock is released by the unlock actuator. The 2 sections of the link sub-assembly fold upward to move the bottom of the yoke forward during the MLG retraction sequence. The links are moved into a mechanical lock position by the downlock springs during the MLG extension sequence. Two lock springs keep the links in the mechanical lock position when the MLG is extended. The stabilizer brace allows for the installation of a ground lock pin when the MLG is extended.

## *Vibration and investigative testing of landing gear*

At the scene of the occurrence, the right MLG rear doors were found to be in the open state, indicating that the SSV had commanded them to open.

As soon as the aircraft was recovered to a hangar for inspection and repairs, both of the landing gears and all involved systems were inspected and their function checked while the aircraft was on jacks. Both shock struts were found to be correctly serviced, and all grease points were adequately lubricated. No components had visible damage, except for the failed retraction actuator that retracts and extends the landing gear. It had failed under a compression load due to the weight of the aircraft when the gear came unlocked. The retraction actuator is not designed to hold the gear extended, but only to move it when airborne. It was replaced with a serviceable unit for testing purposes. The nose landing gear was cleaned and repaired to the extent necessary, and new tires were put on the aircraft, also to allow testing. The landing gear was operated to the retracted and extended positions numerous times with the aircraft auxiliary hydraulic pump and, later, a floor-based hydraulic cart. Both the main and the nose landing gear systems performed correctly and within specifications.

Repeated checks showed that the gap in the stop pads of the stabilizer brace lock link at the transition point between a safe (green) and unsafe (red) signal was 0.041 inches. The 2 proximity sensor gaps were also consistently at a gap of 0.067 inches when reaching a "FAR" condition, which illuminated a gear-unsafe (red) indication in the cockpit. Test results for both main gears were virtually identical; all gaps were within specification and tolerances. The landing gear and components were then removed from the aircraft and shipped to the manufacturer's facilities for later testing.

The number 3 wheel with the blown tire was tested for the level of imbalance at the time of the occurrence. To balance the wheel and tire assembly, 6.5 pounds of counter-balance weight was added 12 inches from the centre of the wheel assembly at the location of the hole in the tire. This equated to an imbalance measurement of 1248 ounce-inches (6.5 pounds × 16 ounces/pound × 12 inches) or 0.29*g*.

The SSV was qualified, according to United States military standard MIL-STD-810F,[13] to a random vibration with an average of no less than 1.5*g* and peaks of 8*g*. The qualification standards do not require operational checks to be performed during dynamic vibration testing, but only after the vibration is completed.

Vibration tests on the SSV during operation, on the stabilizer brace, and on the full gear were performed for this investigation and are described in this section. Such tests had never been carried out before, nor are they specifically required for certification. The CARs requirements list no vibration criteria for the certification of aircraft, other than references to buffeting in flight conditions under Part V, Standard 525.251: Vibration and Buffeting. Airworthiness Manual Section 525.1309 and its associated advisory material require that any component manufacturer conduct tests designed to ensure that the component performs its intended function or functions under any foreseeable operating condition. They also require that any malfunction of the component that may affect the safe flight, landing, or operation of the aircraft under adverse conditions be improbable. There is no specific reference to dynamic vibration testing in the Airworthiness Manual.

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13 MIL-STD-810, *Environmental Engineering Considerations and Laboratory Tests* (01 January 2000), is a United States military standard that specifies test conditions for the design of components.

The vibration tests performed on the SSV for this investigation involved a maximum vibration setting of 2.26*g*, as derived from RTCA DO160F;[14] spectrum "T" (vibration response spectrum) of 35 Hz (limited to a frequency range from 10 Hz to 35 Hz, corresponding to the range of normal landing speeds for the aircraft); and the calculated load that the SSV was subject to on the occurrence aircraft. The testing did not account for landing gear resonance found later, during full-scale testing of the landing gear. During the vibration testing, the voltages to the SSV were gradually reduced until the SSV dropped hydraulic pressure, which occurred at 4 volts. A full acceptance test protocol (ATP) bench check was done, and the SSV passed. The SSV performed as qualified and required for it to function in the MLG extension/retraction system.

The PSEU was checked for fault codes after the accident and later underwent full ATP checks at the manufacturer's facility under supervision of TSB Laboratory personnel. No faults were found.

The landing gear stabilizer brace was also inspected and tested according to the ATP at the manufacturer's facilities. The inspection revealed no anomalies other than a slightly larger-than-normal over-centre measurement; however, this was normal and due to in-service wear. The stabilizer brace was also subjected to rigorous vibration tests; the plan was to subject it to a maximum of 0.29*g* in the vertical direction (representing the load on the stabilizer brace with the 1248-ounce-inch tire imbalance at 35 Hz). A few resonance sweeps were performed, as well as a number of dwells at various frequencies up to 0.4*g*; very noticeable vertical vibration at the centre of the brace could be seen at this *g* level, at the resonant frequency. This was followed by the test spectra according to the planned test. In addition to the test plan, in an attempt to force the brace to unlock, additional cases were run that were not representative of the loads on the brace during the incident. With the unlock actuator in the pressurized condition, the brace was tested at accelerations up to 2*g*. None of the test cases that were applied resulted in the stabilizer brace coming out of lock; however, the pressurized test jig attachments prevented this in any event.

A holding fixture was fabricated at the landing gear manufacturer's facility; a full main-gear assembly was mounted on it and outfitted with numerous sensors and accelerometers. Over several weeks, a full range of tests was carried out, in which the number 3 tire was spun at various speeds and imbalance weights to obtain data for computer modelling and vibration analysis. It was found that the landing gear assembly mounted on the holding fixture was noticeably more rigid than it would have been if it had been mounted in a nacelle on the wing of the aircraft.

These tests were conducted with the landing-gear shock strut

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[14] Radio Technical Commission for Aeronautics, DO-160F, *Environmental Conditions and Test Procedures for Airborne Equipment* (06 December 2007), is a standard for the environmental testing of avionics hardware.

- at a fully extended stroke (approximating its extension when the aircraft is still in the air or at touchdown),
- at 4 inches of compression (close to a WOW indication),
- at 8 inches (expected compression when the landing gear collapsed during the occurrence flight), and
- at 11.8 inches (approximating the full weight of the aircraft on the gear).

The wheels were spun at various speeds, working up to the wheel speed encountered during the landing of the occurrence aircraft (1350 rpm, which equates to approximately 118 knots).

At 8 inches of strut compression, the same imbalance weight, and a tire rotational speed of 1215 rpm (as encountered during the occurrence aircraft landing conditions), a resonance resulting in a severe vibration was observed. During this vibration, the downlock proximity sensors inductance was oscillating and momentarily dropping below the trip point between “NEAR” and “FAR”. This would have been interpreted by the PSEU as a signal that the gear was in a transitional phase, and the PSEU would have subsequently commanded the SSV to release the hydraulic pressure on the downlock side of the unlock actuator. This testing, with only return pressure (approximately 50 psi) on both the retraction and downlock actuators, resulted in a loss of a downlock condition of the stabilizer brace and a subsequent partial retraction of the landing gear. When the same conditions were run with 3000 psi (normal aircraft system pressure) in both actuators, the result was significant motion of the stabilizer brace toward unlock, but the pressure in the unlock actuator successfully prevented unlocking. This again resulted in sufficient oscillation of the downlock sensor target gap to indicate “FAR” to the PSEU.

## *Other information*

On 14 March 2015, on a Republic Airways Bombardier DHC-8-Q400 aircraft (registration N191WQ, serial number 4191), a number 2[15] MLG tire blew out on takeoff roll for a scheduled flight from Denver International Airport (KDEN) to Kansas City International Airport (KMCI). A runway inspection confirmed tire debris on the runway. The crew then elected to declare an emergency and to return to Denver, where the aircraft landed safely. The flight data recorder information was made available to the TSB, and the subject tire was examined at the TSB Laboratory. Data from both the takeoff and landing were used for a comparative analysis to assist in this investigation. The recorded flight data were very similar throughout the landing roll. An examination of the tire revealed a greater imbalance, measured at 8.4 pounds or an equivalent value of 1613 ounce-inches, than in the Jazz Aviation occurrence. The Republic Airways incident did not result in an unlock and collapse of the landing gear.

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15 The number 2 tire was situated in the left inboard position.

On 08 March 2015, a Spice Jet Bombardier DHC-8-Q400 (registration VT-SUA) on a scheduled flight from Bangalore Airport (VOBG), India, to Hubli Airport (VOHB), India, hit a runway light during its runway roll, followed by a ruptured number 1 tire, a runway excursion, and a collapse of the left landing gear. In this occurrence, the aircraft tire was cut, but no tire material was missing; this would not have resulted in a significant imbalance. The landing gear was partially examined on-site; however, the reason for its collapse was not determined to any degree of certainty. Examination of recorded flight data from this occurrence showed almost exactly the same vibrations and conditions as in the Jazz Aviation occurrence that is the subject of this report, but the vibrations were likely from the impact. The resonant response in the landing gear was the same as in the Jazz Aviation occurrence.

## *TSB laboratory reports*

The TSB completed the following laboratory reports in support of this investigation:

- LP237/2014 – DFDR QAR Download and Analysis
- LP 238 / 2014 – CVR Download and Transcription
- LP239 / 2014 – Recovery, Remote Data Concentrator
- LP242 / 2014 – Examination of MLG and Tire
- LP261 / 2014 – Landing Gear System Examination
- LP074 / 2015 – Examination of Failed Tire (Republic Airways Tire)

# *Analysis*

The flight crew was certified and qualified for the flight in accordance with existing regulations. The flight crew and cabin crew conducted all operations following the applicable manuals, and operational issues are not considered to have been a factor in this occurrence. All crew members were well rested, and fatigue or other human factors are not considered to have contributed to the occurrence.

Weather was suitable for visual flight, and the runway condition was bare and dry; therefore, weather factors are not considered to have contributed to the accident.

All records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

An unexpected high rotational imbalance was created on the number 3 tire when it failed during takeoff. During landing, the failed number 3 tire was spun by contact with the ground and was maintained at a rotational speed that was the same as or very close to one of the natural frequencies of the main landing gear (MLG). This caused the lock links to trigger (through the proximity sensors gap) the proximity sensor electronic unit (PSEU) to de-energize the solenoid sequence valve (SSV), thereby relieving system pressure from the extend port of the unlock actuator. In this condition, the excessive vibration then caused the lock links to overcome the force from the downlock springs and unlock the stabilizer brace as a result of gear dynamics, which led to collapse of the right MLG.

If there are no specific requirements for dynamic vibration testing of components or completed airframes, there is a risk that similar or other aircraft systems could fail during high-vibration conditions.

The propeller blades broke up when they struck the runway. While there is a reinforced area on the fuselage to protect against ice shed from the propeller blades, it is not designed to stop portions of failed propeller components from entering the cabin.

The evacuation was carried out efficiently. The delay in opening the 1L exit and the momentary delay due to a passenger attempting to take carry-on baggage did not significantly affect the time to evacuate. After the prompt evacuation, there was a waiting period on the ground as the flight crew and cabin crew attempted to gather the passengers and keep them together. There was no vehicle or infrastructure immediately available to the crew to help them accomplish this. The passengers were placed on buses approximately 13 minutes after evacuation, and no injury or worsening of previous injuries was attributed to this waiting time.

# Findings

## Findings as to causes and contributing factors

1. The number 3 tire ruptured on takeoff, most likely as a result of impact with a hard object.

2. During landing, the failed number 3 tire was spun by contact with the ground and was maintained at a rotational speed that was the same as or very close to one of the natural frequencies of the main landing gear. This caused the lock links to trigger the proximity sensor electronic unit to de-energize the solenoid sequence valve, thereby relieving system pressure from the extend port of the unlock actuator.

3. The excessive vibration caused the lock links to overcome the force from the downlock springs and unlock the stabilizer brace as a result of gear dynamics, which led to collapse of the right main landing gear.

## Findings as to risk

1. If there are no specific requirements for dynamic vibration testing of components or completed airframes, there is a risk that similar or other aircraft systems could fail during high-vibration conditions.

## Other findings

1. Short-radius turns with hard braking may cause an extreme shearing force on the tread area and on the sidewalls of the number 3 tire in particular, because it is the pivot point.

# Safety action

## Safety action taken

### *Jazz Aviation*

- Immediately after the accident, management of Jazz Aviation decided to mitigate any possible future damage from MLG tires and no longer use retreaded tires on the MLG of its DHC-8-Q400 fleet, effective 10 November 2014.
- Jazz Aviation has made changes to its DHC-8-Q400 Line Indoctrination Guide – Pilot Line Indoctrination, items 14 and 30, to avoid the use of braking and tire pivot whenever possible. The company has also made changes to volume 2 of its aircraft operating manual and issued a memo (Q400 Memo 2014-131) that addresses Q400 gate arrival and departure taxi techniques, in order to lessen stresses on the main landing gear tires.

### *Other*

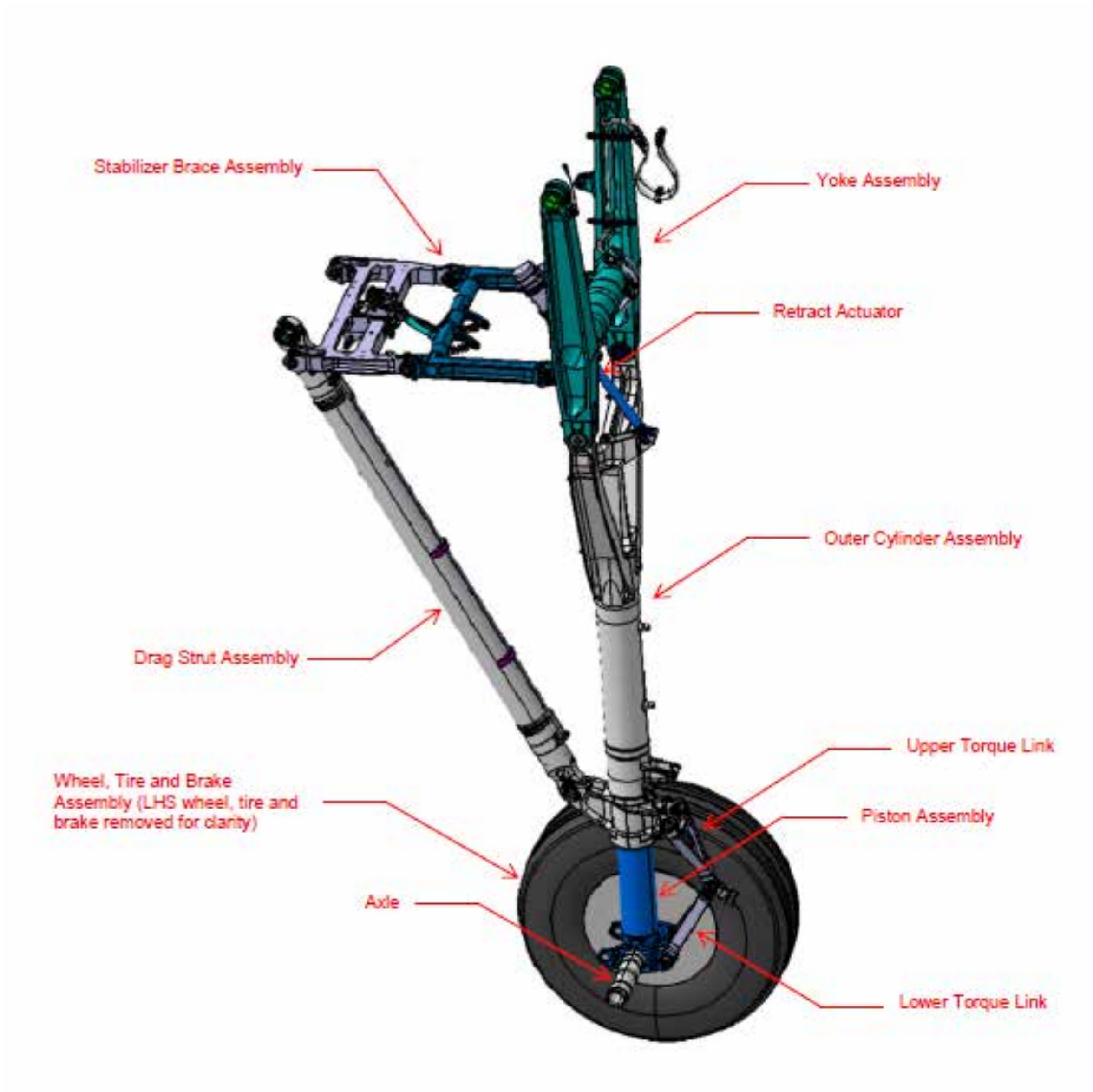
- Other operators that use this aircraft have changed operational procedures to mitigate effect of the sharp right turns on the ramps near the gates in order to lessen the extreme shear loads primarily affecting the number 3 tires.

*This report concludes the Transportation Safety Board's investigation into this occurrence. The Board authorized the release of this report on 9 March 2016. It was officially released on 6 April 2016.*

*Visit the Transportation Safety Board's website (www.tsb.gc.ca) for information about the TSB and its products and services. You will also find the Watchlist, which identifies the transportation safety issues that pose the greatest risk to Canadians. In each case, the TSB has found that actions taken to date are inadequate, and that industry and regulators need to take additional concrete measures to eliminate the risks.*

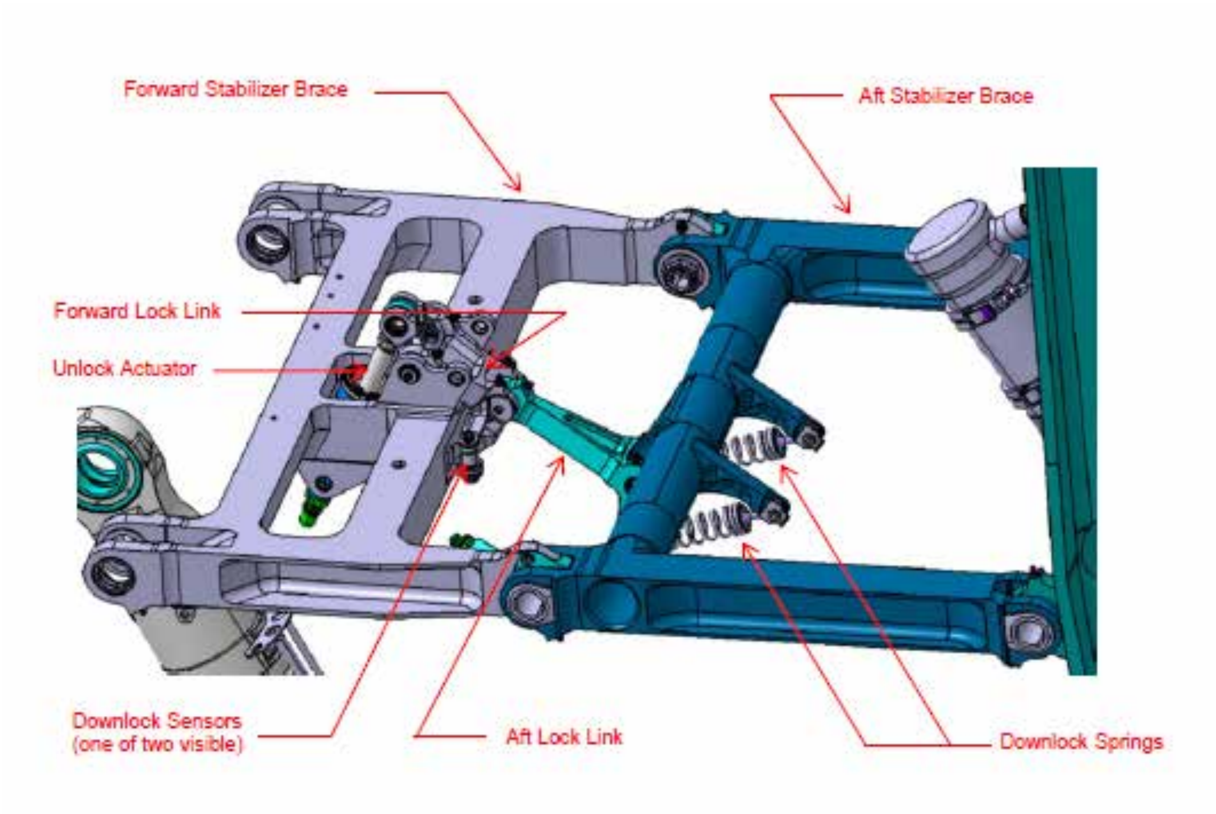
# Appendices

## Appendix A – DHC-8-Q400 main landing gear and major sub-assemblies




Source: UTC Aerospace Systems

**Zoomed view of the main landing gear stabilizer brace assembly (part no. 46400-27/-29) (Source: UTC Aerospace Systems)**




The stabilizer brace assembly, which is a relatively complex mechanism, is comprised of the following major sub-components:

- The forward and aft stabilizer braces, which are the two largest components in the assembly. When the MLG is down-and-locked, these two components are held slightly over-centre relative to each other by the lock link assembly, thereby stabilizing the entire landing gear (which is a mechanism in its own right).
- The forward and aft lock links, which are the two smaller link-like components in the assembly. When the MLG is down-and-locked, the position of these two components relative to each other forms a lock that holds the forward and aft stabilizer braces approximately in line.
- Two downlock springs, which are intended to place and retain the lock links in a locking position without the need for hydraulic power.
- The unlock actuator, which unlocks the lock links and pulls the stabilizer brace out of the over-centre position. This, in turn, allows the stabilizer brace assembly to fold, thereby allowing MLG retraction.[16]

16 The text accompanying this diagram is reproduced here with permission of UTC Aerospace Systems.